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Materiel Test Procedure 5-2-513
White Sands Missile Range

U. S. ARMY TEST AND EVALUATION COMMAND
COMMON ENGINEERING TEST PROCEDURE

MISSILEBORNE ACCELEROMETER TESTS

1. OBJECTIVE

The object of this test is to determine limitations and characteristics of missileborne accelerometers.

2. BACKGROUND

Because of exacting requirements placed on missileborne accelerometers, laboratory engineering tests are performed to determine limitations and other characteristics which may affect their operation. The results of these tests will make it possible to eliminate unreliable accelerometers, which could cause failure of missile flight. Test data collected from tests outlined in this pamphlet are needed for use in trajectory analysis studies and missile flight simulation based on realistic program parameters. See Appendix A for a general description of various types of accelerometers.

3. REQUIRED EQUIPMENT

a. Thermometer
b. 500 volt megger
c. Shake table (electromagnetic or mechanical)
d. Magnetic tape recorder
e. Ohm meter
f. Oscilloscope (dual trace)
g. Resistance bridge
h. Variable frequency sine wave generator
i. Precision phase angle measuring device
j. Weights equal to accelerometer weight
k. Bell jar and suitable means for creating a vacuum
l. Dial indicator micrometer
m. Centrifuge table with accurate means of contol and precision built mounting fixture.
n. Indexing head or equivelant equipment
o. Brush or Sandborne recorder or any recorder of equal sensitivity and accuracy.
p. Hardware required to mount the accelerometers, clamps, blocks, etc.
q. Precision voltage measuring device; i.e., precision potentiometer, precision digital voltmeter.
r. Transient blow fixture
s. Micrometer
t. Nullout box
u. Buzzer
v. Adequately equipped laboratory

w. Standard or proof accelerometer
x. Electrodynamic type shaker
y. Mirror
z. Crystal vibrator
aa. Monochromatic light source (preferably a mercury vapor light)

4. REFERENCES

A. ASA Z32-1950, Abbreviations for Use on Drawings, American Standards Association, New York, N.Y. 1950.
B. AFM 52-31, Guided Missiles Fundamentals, 1950
C. ST-100 Vibration Exciter, International Telephone and Telegraph Corporation, San Dernando, California
D. Dynamic Instrumentation, Endevco Corporation, Pasadena, California
E. MIL-E-5272, Evnironmental Testing Aeronautical and Associated Equipment, General Specification 4.

5. SCOPE

5.1 SUMMARY

The procedures portion of this MTP is composed of tests common to all linear accelerometers followed by procedures applicable only to spring-mass type accelerometers with d-c potentiometer pickoff, gyro type integrating accelerometers and piezoelectric type accelerometers. The procedures are somewhat general in extent so that they can be used as a guide toward gathering and evaluating data from many types of accelerometers together with the accuracy required in testing. Required accuracies generally are called out by the applicable Missile Purchase Description (MDP) or military specification. The following tests are described.

a. Visual Examination - The purpose of this test is to determine any obvious faults, poor workmanship, damage in shipping, and general appearance and conformity to the expected standards..

b. Resistance and insulation - The purpose of these tests is to give a quick indication of electrical malfunction or component failure.

c. Frequency Response and Damping Factor - The purpose of this test is to determine the frequency range within which an accelerometer will develop an output signal of constant amplitude when an acceleration of constant amplitude is applied to the input. Damping factor, dynamic transfer function, natural frequency and amplitude response are also checked.

d. Null Offset E_n and Null Uncertainty - The purpose of this test is to determine the null offset and null uncertainty error component which will during flight, have an effect on the position of the missile where high accuracy inertial guidance systems are used.

e. Sensitive Axis Alignment - The purpose of this test is to ensure the alignment of the sensitive axis of an accelerometer with respect to the reference surfaces. Alignment becomes an important factor when dealing with high accuracy inertial guidance systems.

f. Linearity - The purpose of this test is to determine the accelerometer scale factor and linearity error.

g. Scale Factor Constancy and Repeatability - The purpose of this test is to determine scale factor constancy and repeatability with changing conditions of environment and temperature, aging, etc.

h. Cross Coupling - The purpose of this test is to determine the error component due to any cross axis acceleration misalignment error.

i. Pickoff Scale Factor and Spring Constant - This test is performed to determine the mechanical spring rate and the electrical to mechanical stiffness ratio in the feedback system of the accelerometer.

j. Quadrature Voltage - The purpose of this test is to determine the extent of quadrature and phase shift angle in those accelerometers which have an a-c type pick-off.

k. Case Leaks - The purpose of this test is to determine whether or not the accelerometer has a case leak.

l. Tests Under Specified Environment - Test under specified environment are those tests which are on the accelerometer at other than laboratory ambient conditions.

m. Dielectric Tests - The purpose of this test is to give a quick indication of electrical malfunction or component failure.

n. Spring-Mass Type Accelerometers with D-C Potentiometer Pickoff - The following tests are peculiar to spring-mass type accelerometers with d-c potentiometer pickoffs.

1) Potentiometer Resolution - The purpose of this test is to determine the potentiometer resolution by actually counting the number of active wire turns (called wires)
2) Sensitivity Resolution - The purpose of this test is to determine the actual minimum change in acceleration to which the accelerometer will respond.
3) Static Friction - The purpose of this test is to determine the minimum amount of acceleration which must be applied to the accelerometer to obtain a reading when the accelerometer is at null.
4) Plus and Minus lg Static Calibration - Determines the voltage change for ± lg acceleration
5) Swept Length of Potentiometer Wiper - This test is conducted to determine the swept length per g of the potentiometer wiper.
6) Calibration, Linearity, and Repeatability - This test determines repeatability and linearity characteristics, location of calibration line, and hysteresis error.
7) Width of Potentiometer Wiper - This test measures the width of the wiper in terms of the number of wires of width.

o. Gyro Integrating Type Accelerometer - The test described are peculiar to this type of accelerometer and shall be accomplished in addition to those tests common to all linear accelerometers.

p. Piezoelectric Type Accelerometers - Two methods for testing this type of accelerometer are described:

1) Method one - low frequency
2) Method two - high frequency

5.2 LIMITATIONS

6. PROCEDURES

6.1 PREPARATION FOR TEST

6.1.1 General

The following general procedures shall be used throughout the various phases of testing:

a. Particular attention shall be given to the sequence of testing in order that the effects of one test will not adversely affect subsequent tests, and so that any information needed from a prior test shall be available.

b. Standard operating procedure (SOP) safety precautions shall always be observed and test conductors shall be completely familiar with manufacturer's operating manuals pertaining to test equipment used.

c. Instruction manuals shall be followed closely in aspects of operational safety to ensure against high voltages, burns, shock, etc.

d. When in doubt, test personnel shall consult references mentioned in these test procedures or consult their supervisor rather than risk ruining test data through lack of instructions or through misunderstanding.

e. Each accelerometer tested under these procedures shall have a log book. (Standard engineering notebook shall be used).

f. In this log book shall be recorded all the test history of the individual accelerometer such as:

1) Total number of wiper sweeps, running time, etc., and all test data

g. Entries shall be made in this log book before and after the test, as applicable.

6.1.2 Instrumentation

a. Where at all possible, test personnel shall limit themselves to the specified test facilities insofar as they have been proven effective for the specific test through previous use.

b. The operator of these test instruments shall familiarize himself thoroughly with their use and adhere to the manufacturer's operating instructions.

c. Instrumentation should be such that output and input measurements should be on the order of ten times as accurate as the requirements of the function being measured.

6.1.3 Test Configuration

a. The test configuration for each individual test shall not be destroyed or molested until raw data has been reduced and/or plotted.

b. All accelerometers shall be given any specific test with one test configuration before proceeding to the next type of test. This procedure will help in correlating test findings.

6.1.4 Initial Checkout

a. Refer to all available information, MPD's and other sources to determine what initial steps shall be taken, if any to prepare the accelerometer in question for the test to follow.

b. The extent of such investigations shall depend somewhat upon the experience of test personnel and what is felt to be necessary and shall be left to a great extent to the discretion of test personnel or the engineer responsible for the test.

6.2 TEST CONDUCT

6.2.1 Visual Examination

a. Upon receipt of any accelerometer and auxilliary equipment, conduct a visual inspection.

b. Use associated drawings and military specifications as guides in conducting the examinations.

c. Observe and record the following:

1) Any obvious faults
2) Poor workmanship
3) Damage in shipping
4) General appearance
5) Non-conformity to the expected standards

6.2.2 Resistance and Insulation

NOTE: Caution shall be used when making the high voltage resistance test to guard against the possibility of damage from excessively high voltage being applied to susceptible components. The value limits are generally to be found in the MPD or determined from circuit diagrams.

a. The unit shall be left completely de-energized in the test locality for a sufficient length of time to allow all its parts to attain ambient temperature.

b. The room temperature shall be read and recorded adjacent to the unit.

c. MPD's and military specifications shall be referred to in establishing guide lines for making this test, although tests are not to be restricted to these specifications if more thorough investigation is warranted.

d. Depending on the accuracy required an ohmmeter or bridge type resistance measuring device shall be used to measure point to point resistance values.

e. Record the resistance values measured.

f. Using a 500 volt d-c megger measure and record insulation between internal circuits and case and between isolated circuits.

6.2.3 Frequency Response, and Damping Factor

Several methods are described for the following tests. The method used should depend on the accelerometer being tested, test requirements, and to the discretion of the test personnel or the test engineer. During each frequency response test the frequency of each run and the time taken to make the run shall be recorded.

6.2.3.1 Frequency Response - Sine Wave Generator Method

In some types of accelerometers especially the servo-force balance type only the amplitude versus frequency is of interest. The following technique may be used with this type of accelerometers.

a. The accelerometer shall be connected to a variable frequency sine wave generator.

NOTE: The variable frequency sine wave generator is used to pass an a-c current through the restoring element of the pendulum, i.e., the torque coil, thereby simulating an acceleration. This causes the pendulum to vibrate as it would under sinusoidal acceleration.

b. The simulated input g level shall be adjusted to some value within the vicinity of 10 to 20% rms value, of the full range of the accelerometer and maintained at this level throughout the test.
c. The frequency of the sine wave generator is varied through the frequency range in increments of 5 or 10 cycles.
d. An oscilloscope shall be used to check the input, output, phase shift, frequency and amplitude of the accelerometer signal.
e. The voltage of the accelerometer output is recorded at each incremental step of the sine wave generator.

6.2.3.2 Frequency Response - Shaker Method

The shaker method is the most common way to excite the accelerometer for a frequency response tests.

a. The accelerometer shall be attached mechanically to an accurate shake table (electromagnetic or mechanical) by a low impedance mechanical coupling such that the sensitive direction of the accelerometer is parallel to the travel direction of the shake table.
b. An oscilloscope shall be connected to the accelerometer to read input, output and phase difference.
c. Adjust the shake table to produce about 30 percent rms of the maximum range of the accelerometer.

NOTE: The 30 percent input is to avoid the possibility of the mass striking the limit stops at resonance if the accelerometer proves to have low damping.

d. Adjust the shake table at the lowest frequency of interest, this would be in the frequency range where the response is known to be flat.

e. Readings of amplitude ratio and phase shift versus frequency shall be recorded while the frequency is stepped through the specified frequency range in increments of 5 to 10 cycles.

6.2.3.3 Resonant Natural Frequency

a. The accelerometer shall be mounted as described in paragraph 6.2.3.2.

b. Connect the output of the accelerometer into the Y-channel of a cathode ray oscilloscope (CRO) and the signal monitor from the shaker input into the X-channel of the CRO to obtain a lissajous pattern.

c. Start the shaker table to operate at 5 or 6 cps and the amplitude of both CRO channels adjusted from some convenient trace.

NOTE: The CRO pattern will be circular or slightly eliptical.

d. Increase the frequency of the table oscillations and at the same time vary the gain of the CRO amplifiers to keep the same lissajous pattern in proportion.

e. Continue to increase the frequency slowly until the ellipse completely closes to form one line at a slant of approximately 45°.

f. The frequency on the dial of the shaker oscillator shall be read and recorded as F_n (natural frequency of the accelerometer).

6.2.3.4 Damping Factor

The purpose of this test is to determine the percent of critical damping.

NOTE: Damping factor may be determined by plotting a Bode curve of the frequency response, then fitting this curve to a family of frequency response curves of a simple resonant system or it may be determined as follows:

a. Rigidly mount the accelerometer in one stirrup of a transient blow fixture.

b. In the other stirrup of the fixture mount an equal weight (not an accelerometer).

c. Energize the accelerometer input terminals with the proper voltage.

d. Connect the output to a cathode ray oscilloscope (CRO) or recorder (d-c- amplifier).

e. Displace the stirrup holding the accelerometer about 34° or 40° using the left hand.

f. Suddenly let go of the stirrup and allow it in a free fall to strike the counter weight.

NOTE: The counter weight will be driven to the right, but the stirrup containing the accelerometer will come to a dead stop.

g. The stirrup containing the counter weight shall be grasped with the right hand to prevent it from falling back against the stirrup containing the accelerometer thereby causing a series of bounces.

h. If the stirrup containing the accelerometer does not come to a dead stop at the point where it strikes the other stirrup, adjust an attached sliding brake pad until it does.

i. Adjust the gain of the CRO for 3/4 - or 1-inch deflection

j. After adjustments are made repeat steps e through g, and observe and record the amplitude of the step input deflection and amplitude on CRO of the first over-shoot.

k. Repeat step j several times to note if results are repeatable. if so record the damping value for each attempt.

6.2.3.5 Transfer Function

When system parameters are not readily available, an approximation to the transfer function shall be derived from frequency response data. (Paragraph 6.2.3.2 and 6.2.3.3).

NOTE 1: It is necessary to obtain reliable phase and amplitude data and a thorough knowledge of feedback systems is required to employ these techniques.

NOTE 2: In the spring-mass system, the transfer function can be developed through Newtonian mechanics, or where system parameters are known this may be done for the force balance type.

6.2.4 Null Offset (En and Null Uncertainty)

The following procedure to determine null offset employs the technique of plunging, better known as the 180 degree ± g test.

NOTE: Null offset is a constant peculiar to each accelerometer and should not be confused with null uncertainty which is the random change of null offset with time. No attempt shall be made to separate the two effects, as in the usual situation there is a large null offset superimposed on a small null uncertainty.

a. Orient the accelerometer on a dividing head so its sensitive axis is perpendicular to the gravity field vector and so that the output is exactly zero, or at least the minimum.

b. Record the voltage as E_1.

c. Rotate the accelerometer through an angle of exactly 180° from its position in step a. (Rotation shall be about a horizontal axis which is normal to the sensitive axis).

d. Record the output as E_2.

e. When making high accuracy measurements the error tolerance caused from the following assumptions, shall be considered and recorded.

1) The sensitive axis is perpendicular to the axis of rotation.
2) Cross coupling effects are negligible in a one g field.
3) The direction of the sensitive axis in step a, is exactly 180° from that in step c.

6.2.5 Sensitive Axis Alignment

NOTE: Refer to Appendix B for a brief description of sensitive axis alignment, the X, Y and Z axis and the No. 1 and No. 2 planes

6.2.5.1 Alignment in No. 1 Plane (X-Z Axis)

a. Method for accelerometers provided with mounting screw holes or locating notches in the reference surface.

1) Prepare the metal rectangular shaped mounting fixuture with precision screw holes or dowel pins for mounting the accelerometer.
2) Ensure that top and bottom surfaces, end edge surfaces, and side edge surfaces of the mounting fixture are respectively parallel.
3) Ensure that the fixture side edge surfaces are parallel with screw holes or dowel pins mentioned previously. No side or end play shall exist.

NOTE: The degree of accuracy of the parallelisms mentioned can be determined from the callouts of the MPD or specification applicable to the accelerometer under test. Related surfaces shall be parallel to within, at most, 30 seconds of arc.

4) Mount the accelerometer in the precision fixture onto a dividing head such that when the dividing head surface plate is horizontal and level in the N-S and E-W directions, the accelerometer's Y axis is vertical and its X-axis is horizontal and strictly at right angles to the tilt rotating axis of the dividing head.
5) Connect the output of the accelerometer to a suitable precision voltage measuring device.
6) Energize the accelerometer.
7) After suitable warm-up time, monitor the output.
8) Record the output voltage as E_1.
9) Rotate the dividing head a slight amount in each direction about its tilt axis until a zero or minimum output voltage is obtained.
10) Record this voltage as E_2.
11) Read and record as $\emptyset_1$, the angle through which the dividing head was rotated.
12) Restore the dividing head to level as in step 4.
13) Unclamp the mounting fixture and turn end over end, 180°.
14) Reclamp and run steps 4 through 11, record the dividing head angle as $\emptyset_2$.

b. Method for accelerometers not provided with mounting screw holes or locating notches.

This type accelerometer usually is provided a mounting ring or shoulder offset from the case. Small clamping devices called dogs generally are used to effect rigidity between the accelerometer mounting ring and the receptacle into which it fits. Alignment in the X-Z axis does not merit a great consideration in accelerometers with this type mounting. The important object is to truly align the X-axis of the accelerometer in its mounting fixture. This is accomplished in much the same manner as the misalignment error is determined in paragraph 6.2.5.1, a, except that when the accelerometer is oriented and the dividing head leveled as in step 4 of paragraph 6.2.5.1, a, the accelerometer itself is rotated in the fixture until zero or minimum output is obtained. The clamping dogs are then tightened on the mounting ring and a finely scribed index line is etched on the mounting ring and the mounting fixture. Thus, a permanent alignment index is obtained permitting removal and replacement of the accelerometer at any time.

6.2.5.2 Alignment in No. 2 Plane (X-Y Axis)

Tests for misalignment in this plane are conducted in the same manner as for any type of accelerometer.

a. Adjust the face plate of a dividing head in tilt until its surface plane is vertical and parallel with, and its rotational axis perpendicular to the earth's gravity vector.

b. Mount a precision right angle bracket onto the face plate and place the accelerometer in its mounting fixture on the bracket such that the accelerometer's X, or sensitive axis is parallel to the surface plate to within 1 or 2 degrees. The accelerometer's Y-axis will be parallel with the dividing head rotational (not tilting) axis.

c. Connect the output of the accelerometer to a suitable precision voltage measuring device.

d. Rotate the face plate until the accelerometer output reads zero or null, record both the output voltage and the angular position of the face plate as E_1 and $\emptyset$, respectively.

e. Rotate the accelerometer in orientation by 180 degrees ± 1 or 2 degrees.

NOTE: If the accelerometer is of the type that has a mounting ring, it can be rotated by loosening the clamping dogs.

f. Read and record the output voltage as E_2.

g. Again rotate the face plate until the output voltage again reads zero or null as it did in step c.

h. Read and record the new angular setting of the face plate as $\emptyset_2$.

6.2.6 Linearity

All linearity tests shall be conducted a minimum of three times to achieve good representation of linear characteristics.

NOTE: A matter which shall be given close attention in the testing of high accuracy accelerometers is that of the value of one "g". At different geographical locations the value of one "g", will vary from the norm which will affect scale factor correlation between linearity tests conducted when the earth's field is used as one "g" reference and when a centrifuge is used for generating higher level accelerations. The acceleration value in "g"'s shall be expressed as cm/sec^2.

6.2.6.1 Linearity to Plus and Minus 1 g

a. Properly position the accelerometer on an accurate dividing head such that the accelerometer's Z-axis will be parallel with the dividing head rotational axis when that axis is horizontal and the dividing head face plate has been tilted such that its plane surface is vertical.

NOTE: The accelerometer's Y, or pivot, axis will also be vertical and parallel with the earth's gravity vector. Under these orientations the mass will swing as a gate and acceleration input to the accelerometer from zero to 90 degrees will always be $g = \sin \emptyset$, where $\emptyset$ = angle away from vertical through which the Y-axis was rotated. $\emptyset$ can be read on the dividing head.

b. Connect the output of the accelerometer to a suitable precision voltage measuring device.
c. Energize the accelerometer after it is properly oriented. The output will read zero or null (E_n).
d. Rotate the face plate 90 degrees; since $g = \sin \emptyset$ an acceleration of 1g will now be imparted to the accelerometer.
e. Read and record the output voltage as E_1.
f. Rotate the face plate an additional 180 degrees; the acceleration input will now be a minus 1g.
g. Read and record the output voltage as E_2.
h. Return the accelerometer to zero g input.
i. Rotate the faceplate clockwise (CW) to 90 degrees, but stop the rotation at intervals of 0.1g and read and record the output voltages.
j. Repeat steps h and i, except rotate the face plate in a counter-clockwise (CCW) direction.

6.2.6.2 Linearity Above Plus and Minus 1g

a. Mount the accelerometer on the arm or table or a rotating centrifuge at some known radius (R) from the centrifuge turn axis such that the X-axis is aligned parallel with the radial direction of the centrifuge.
b. Determine the nominal g range of the accelerometer from the applicable specification or from the manufacturer's literature.
c. Divide this range into no less than 10 equally spaced increments of acceleration.
d. Energize the accelerometer.
e. Connect monitoring instrumentation.

f. Start the centrifuge in rotation.

g. By step operation, adjust the velocity of the centrifuge to obtain the various accelerations required at the increments previously mentioned.

h. At each increment monitor and record the following data:

1) Velocity of centrifuge (W)
2) Radius of gyration (R) from the center of the centrifuge turning axis to the center of gravity (cg) of the accelerometer mass.
3) Voltage output (E_o) of the accelerometer at each increment.

i. Repeat steps b through h except rotate the accelerometer 180 degrees in its orientation to obtain negative acceleration.

6.2.7 Scale Factor Constancy and Repeatability

The random change of accelerometer parameters with time and use is one of the major factors limiting accuracy. There is little which can be done to reduce these errors other than complete redesign of the device. But since the units under consideration are subject to such changes, the best which can be done is to observe the limits of these changes by conducting at least three identical linearity tests and other tests for changing environment and aging.

An initial scale factor K, is determined as outlined in paragraph 6.2.6.1 and6.2.6.2. The accelerometer shall be subjected to conditions of environment, aging, temperature, etc., and is again tested for scale factor.

6.2.8 Cross Coupling

NOTE: Cross coupling is defined as the error component due to any cross axis acceleration misalignment error. Cross coupling is necessarily zero when the accelerometer is subjected to a one g field, but an error of some magnitude will exist, small though it may be at accelerations above and below and one g. The magnitude of cross coupling error is that which remains after allowance is made for null offset, hysteresis and misalignment.

a. The Z-axis of the accelerometer shall be mounted nominally parallel to the radius of a centrifuge, with the sensitive or x-axis exactly perpendicular to the gravitational field.

NOTE: Using a centrifuge to provide the acceleration force will require measuring the rotational speed to within ±2 percent or better. Alignment of the accelerometer with respect to the radius of the centrifuge shall be within, at most, ±30 minutes otherwise the maximum angle error shall be included in calculations. Accuracies are dependent upon the applicable specification requirements.

b. Connect the output of the accelerometer to required test instrumentation.

c. Adjust the velocity of the centrifuge until one g is being applied to the accelerometer's Z-axis.

d. Record the accelerometer output.

e. Repeat steps b and c at ten levels of acceleration throughout the range of the accelerometer.

NOTE: This gives the cross coupling error in the Z direction to get cross coupling error in the other axis (Y-axis); this axis shall be mounted and tested as was done with the Z-axis.

6.2.9 Pickoff Scale Factor and Spring Constant

NOTE: If the accelerometer under test is of the servo captive type i.e., the force balance type, it is necessary to connect the accelerometer in open servo loop mode. Open loop mode simply means taking the restoring coil or torque coil out of the circuit and replacing it with a resistor of equal value.

a. Mount the accelerometer on a dividing head such that the mass is hanging down from its suspension springs and the axis of rotation of the dividing head is horizontal and parallel with the Y-axis of the accelerometer. Denote this orientation as position No. 1.

b. Connect the output of the accelerometer to a suitable precision voltage measuring device.

c. Level the accelerometer null output and record the dividing head setting to be used as the zero reference.

d. Rotate the dividing head through about 8 minutes of arc in each direction from zero reference, stopping at intervals of 1, 2, 4, 6 and 8 minutes.

e. Record the angle of rotation and the voltage output at each interval.

f. Reorient the accelerometer on the dividing head such that the mass is pointing out and now swings as a gate and the dividing head rotational axis is parallel with the accelerometer's Z-axis. Denote this orientation as position No. 2.

h. Repeat step d and e , except this time stop the rotation of the dividing head at the voltage reading increments instead of angular increments.

6.2.10 Quadrature Voltage

At zero acceleration input to the accelerometer, practically all the a-c measured from the pickoff output will be quadrature. The ratio of the quadrative to in-phase voltage will be greatest at zero input to the accelerometer i.e., at null.

a. Orient the accelerometer on a dividing head so its sensitive axis is perpendicular to the gravity field vector and so that the output is exactly E_n as determined in paragraph 6.2.4 and 6.4.5.

b. Connect the output of the pickoff to a suitable phase angle measuring device such as the one shown in Figure 1.

c. Using the instructions for the precision phase angle measuring device determine and record the quadrature and in-phase voltage.

6.2.11 Case Leaks

a. Affix a sensitive dial indicator micrometer to the side of the accelerometer case in such a manner that any expansion of the case will be translated to the dial indicator as displacement.

b. Set dial indicator to zero.

c. Place bell jar cover over set up and connect vacuum pump.

d. Evacuate bell jar to 0.5 inch mercury (hg).

e. Record the reading of the dial.

f. Maintain the pressure in bell jar at 0.5 inch hg for two hours.

g. Record the reading of the dial.

6.2.12 Tests Under Specified Environment

Environmental testing should be accomplished in accordance with the following procedures:

MTP 5-2-589: Dust Tests
MTP 5-2-590: Salt Fog Test
MTP 5-2-591: Rain Tests
MTP 5-2-592: Humidity Tests
MTP 5-2-593: High Temperature with Solar Radiation
MTP 5-2-594: High Temperature tests

6.2.13 Dielectric Tests

NOTE: The instruments used for dielectric tests are so designed and have features such that if an insulation breakdown should occur, the specimen under test would not be damaged. Nevertheless, dielectric tests shall be made at or near the end of the test program to avoid subjecting the specimen to a test hazard which may cause damage, thus nullifying the validity of other tests which may reveal more important operating characteristics of the specimen.

a. The accelerometer shall be left completely de-energized in the test locality for a sufficient length of time to allow all its parts to attain ambient temperature.

b. Room temperature adjacent to the unit shall be read and recorded.

c. A 1000-volt or higher high potential tester shall be connected between isolated circuitry (for example, between the primary and secondary winding of a transformer).

d. Resistance values shall be read and recorded.

6.2.14 Spring-Mass Type Accelerometer with D-C Potentiometer

6.2.14.1 Potentiometer Resolution

NOTE: Caution To avoid damaging the friction balls which drive the rate table, be sure that the clutch is not engaged when mounting the accelerometer or fixture on the table.

a. Mount the accelerometer for positive acceleration on a centrifuge 8 or 9 inches from center (counter balance table).

b. Some type of dither or buzzer attachment to overcome the effects of internal accelerometer friction shall be attached to the accelerometer.

c. The buzzer shall vibrate at 60 or 120 cps and approximately ±0.06g

d. Connect accelerometer output pins into a null-out box (a schematic for typical null-out box is shown in Figure 1.)

e. Energize null-out box with 5 or 6 volts d-c.

f. With zero input to accelerometer, adjust the null-out box to zero by means of the null adjustment potentiometer.

g. Connect a Brush or Sanborn recorder to the tape recorder output plug of the null-out box.

h. Experiment with recorder gain by slowly increasing the input rate to accelerometer and adjusting gain until each wire crossed by the potentiometer will show up on the recorder as stair steps, each horizontal step spanning 2 or 3 millimeters.

i. Reduce input to accelerometer

j. Do not disturb recorder gainbut adjust the stylus centering to the extreme negative side of chart paper.

k. Increase the input rate to the accelerometer slowly and observe that recorder is indicating swept wires in the form of the previously mentioned zig-zag line.

l. When the recorder reaches the extreme positive edge of the chart momentarily hold the input constant and return stylus to negative edge, then resume increasing input. Continue this procedure until the potentiometer end point is reached.

m. Stop recorder chart and reduce input to zero.

n. Turn accelerometer 180 degrees in it's mounting.

o. Set the stylus to the extreme positive edge of chart by means of centering adjustment and start the chart.

p. Start increasing the input to the accelerometer.

q. Repeat steps j through n, except note that the stylus is going negative.

r. Physically count and record the number of positive and negative steps as shown on the chart.

6.2.14.2 Sensitivity Resolution

a. Mount accelerometer on a centrifuge at a 10 inch radius of gyration.

b. Connect the dither or buzzer attachment.

c. Connect and adjust null-out box.

d. Increase the input to 25 percent of normal working range.

e. At this input, re-adjust null-out box to zero while pressing sensitivity switch in determining speed of table.

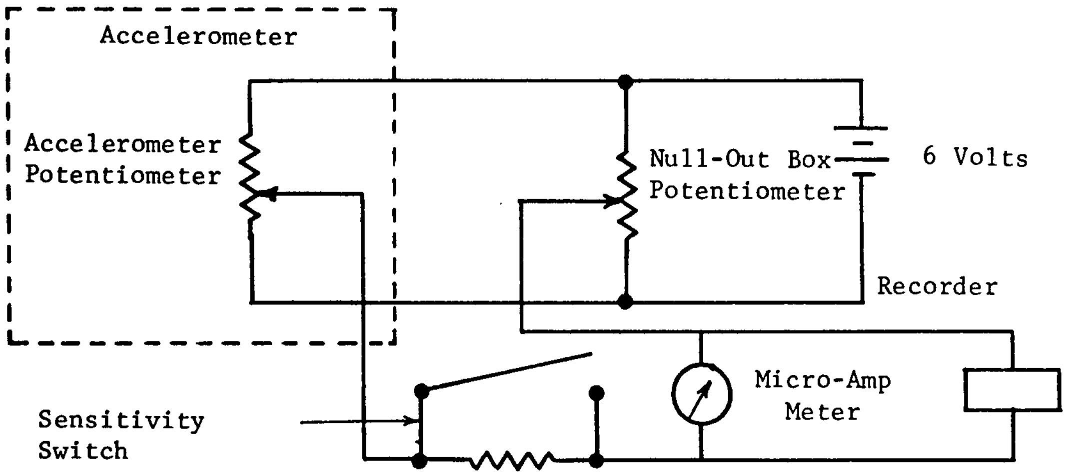

Figure 1. Null-Out Box Schematic

f. Center the recorder stylus and leave gain as it was in step h of paragraph 6.2.14.1.

g. Carefully and slowly increase the input until recorder steps one step.

h. From change in table speed calculate the new g value, and record the difference in acceleration.

i. From the new input, repeat steps g and h.

j. From the second new input, repeat steps g and h a third time.

k. Repeat steps g through j with the accelerator table buzzer or dither energized.

l. Record the same data as in step h noting that data were obtained with buzzer "on".

m. Repeat steps d through l for 50 percent and for 75 percent of the working range.

n. Remove null-out box.

6.2.14.3 Static Friction

a. Mount the accelerometer on an indexing head such that when the indexing head is tilted 90 degrees and the rotating index is on zero, the accelerometer will be perfectly level and under the influence of zero g.

b. Connect the accelerometer to a suitable differential precision voltage measuring device and adjust for null.

c. While depressing the voltmeter sensitivity switch, slowly and smoothly, and in the absence of any tapping or vibration, rotate the indexing head until the potentiometer brush moves to a new location as evidenced by the meter.

d. Read and record the angle through which the accelerometer was rotated.

6.2.14.4 Plus and Minus 1 g Static Calibration

a. Upon completion of the previous test, static friction, continue to rotate indexing head to exactly 90 degrees.
b. Null the voltmeter.
c. Apply a light tapping using a pencil to remove effects of friction.
d. Observe and record polarity of acceleration.
e. Read and record the voltage obtained.
f. Turn the indexing head exactly 180 degrees.
g. Repeat steps c, d and e.

6.2.14.5 Swept Length of Potentiometer Wiper

NOTE: Unless a spare accelerometer is available for dismantling, this test will not be conducted on the particular accelerometer being tested in accordance with this test procedure since the accelerometer is hermetically sealed.

a. Dismantle the accelerometer such that the swept length can be measured.
b. Using a micrometer measure and record the swept length.

6.2.14.6 Calibration, Repeatability, and Linearity

a. Preparation

1) Mount the accelerometer on a centrifuge by means of a precesion built fixture such that the distance from the centrifuge turn axis to the accelerometer center of mass provides a known radius of gyration.
2) Orient the accelerometer to obtain positive acceleration.
3) Counter balance table with another accelerometer or equal weight.
4) A buzzer shall be attached to the centrifuge table if it is not already equipped with one.
5) Buzzer shall be energized before taking each reading.
6) Great care shall be taken not to overshoot the required centrifuge velocity. Since to do so would destroy the effect of hysteresis.

b. Test Conduct

1) Repeat paragraph 6.2.6.2 b, through 6.2.6.2, h.
2) Connect a cathode ray oscilloscope (CRO) across accelerometer, output pins.
3) Set the CRO on a-c and at high gain.
4) Locate the end point by increasing table speed and adjusting the precision voltage measuring device for null until there is no further reflection ofthe null indicating meter when the speed is further increased.

NOTE: Care must be taken to vary table speed slowly to avoid overshooting the end point.

5) Observe the potentiometer wires crossed by the wiper contact by means of the CRO. A momentary spike will occur when a wire is crossed.
6) Slightly decrease and increase the speed alternately to pin point the end point exactly.
7) When the end point has been located :

   a) Read and record the voltage output.
   b) Determine the table speed from the counter and record it.

8) Immediately after completing step 7 set the calibrating dial on the precision voltage measuring device and reduce table speed for null balance at each of the voltage readings which were used for under conditions of increasing speed in step 1.
9) Record data as specified in paragraph 6.2.6.2 h.
10) Continue until zero speed is again reached.
11) Rotate accelerometer mounting fixture 180° to obtain negative acceleration.
12) Repeat steps 1 through 10.
13) Repeat steps 1 through 12 twice.

6.2.14.7 Width of Potentiometer Wiper

If the potentiometer is hermetically sealed, it will not be possible to conduct this test unless a spare is available for dismantling. However, this information is usually found in the manufacturer's literature.

a. Dismantle accelerometer such that resistance measurements of the potentiometer under ambient temperature can be made.
b. Measure and record resistance of potentiometer.
c. Isolate the wiper from the coil.
d. Measure and record resistance of potentiometer with wiper isolated from coil.

6.2.15 Gyro Integrating Type Accelerometer

6.2.15.1 Preparation

a. Test engineers assigned to testing these type of accelerometers shall be well qualified concerning test techniques.
b. Only activities with adequately equipped laboratories shall be assigned tasks of conducting tests on these instruments.
c. All testing shall be accomplished using the applicable military or manufacturer's specifications for guide lines in conducting all tests, espescially the following.
d. When the accelerometer is mounted on a dividing head or on a centrifuge, the gyro spin axis must be truly parallel with the primemover's rotating axis.

6.2.15.2 Test Conduct

The following tests shall be accomplished in addition to those described in paragraph 6.2.1 through 6.2.15

a. Friction and Torque - Determine and record whether or not friction and torque requirements between the accelerometer case and its mounting gimbal are compatible with the torquing capabilities of the servo system.

b. Pressure - If the accelerometer is of the air bearing type obtain from the applicable specification the optimum pressure and investigate and record the following:

1) The effects of over pressure
2) The effects of under pressure
3) Reliability of the pressure operated switch if one is provided.

NOTE: A pressure switch if used, is adjusted such that at falling pressure, the electrical power circuit is opened in time to allow the wheel to coast to a stop before inner gimbal damage or scoring occurs.

c. Linearity of Precession -

1) Subject the mass unbalance to a constant acceleration at 1g or below or above 1 g using a centrifuge.
2) Check rate of precession by timing and recording the time for revolutions of the accelerometer's case about its gimbal.
3) Linearity of precession shall be accomplished by timing in seconds and recording the time for 1/4 revolutions, or smaller fractions of revolutions.

d. Drift

1) Position the accelerometer in both directions through three mutually perpendicular planes and check for drift during a specified period of time for each position.
2) Record the amount of drift if any at each position.

e. Wheel Current

1) Measure and record the gyro wheel current
2) Measure and record time for the motor to come up to synchronous speed as well as its coast-down-to-stop-time.

6.2.16 <u>Piezoelectric Type Accelerometers</u>

Two methods of testing and calibrating are described for this type of accelerometer, ie., low frequency (16 to 2000 cps) and high frequency (2000 cps and up). Ranges of 100 g's are not unusual for the piezoelectric type accelerometers.

6.2.16.1 First Method, Low Frequency

a. Place the unit under test side by side with a standard or proof accelerometer on the head of an electrodynamic type shaker.

b. Mount the shaker on a concrete and block (at least 10 times as heavy as shaker) on suspension springs.

c. Divide the desired frequency into 20 or more equally spaced intervals.

d. Connect the output of both accelerometers to precision voltage measuring devices.

e. Start the shaker in vibration at the desired g level of vibration which is maintained constant using the standard as the controlling device.

f. Operate the shaker through the frequency range and record the following data at each of the intervals of frequency :

1) The output of both accelerometers
2) Frequency of shaker

6.2.16.2 Second Method, High Frequency

a. Mount the accelerometer and a mirror on the flat surface of a vibrating crystal vibrator, such that the mirror is on top of or beside the accelerometer.

b. Place the vibrator on a concrete block (at least ten times as heavy as vibrator)

c. Connect the output of the accelerometer to the precision voltage measuring device.

d. Filter and focus on the mirror a monochromatic light preferably mercury vapor light.

e. Energize the vibrator through a desired range of frequencies divided into 20 or more equally spaced intervals.

f. Record the following data at each interval:

1) Output of accelerometer
2) Frequency of vibrator
3) Number of fringes observed

6.3 TEST DATA

6.3.1 Preparation for Test

6.3.1.1 General

a. All the test history of the individual accelerometer such as total number of wiper sweeps, running time, etc., shall be recorded.

6.3.1.2 Instrumentation

No data recording required

6.3.1.3 Test Configuration

No data recording necessary

6.3.2 Visual Examination

The following data shall be recorded during visual examinations:

a. Any obvious faults
b. Poor workmanship
c. Damage in shipping
d. General appearance
e. Non-conformity to the expected standards

6.3.3 Resistance and Insulation

a. Room temperature adjacent to the unit shall be recorded.
b. Record the point to point resistance values measured.
c. Record the insulation values measured.

6.3.4 Transfer Function, Frequency Response and Damping Factor

6.3.4.1 Preparation

Record the frequency of each run and the time taken to make the run.

6.3.4.2 Frequency Response-Sine Wave Generator Method

The voltages of the accelerometer output shall be recorded.

6.3.4.3 Frequency Response-Shaker Method

Readings of amplitude ratio and phase shift versus frequency shall be recorded.

6.3.4.4 Resonant Natural Frequency

Record the natural frequency as F_n.

6.3.4.5 Damping Factor

Record the amplitude of the step input deflection and amplitude on CRO of the first-over shoot.

6.3.5 Null Offset (E_n) and Null Uncertainty

a. Record the output voltage as E_1.
b. Record the output voltage as E_2.
c. When making high accuracy measurements the error tolerance shall be recorded.

6.3.6 Sensitive Axis Alignment

6.3.6.1 Alignment in No. 1 Plane

a. Record all output voltages as E_1 or E_2.

b. Record the angles Ø, and Ø2 through which the dividing head was rotated.

6.3.6.2 Alignment in No. 2 Plane

a. Record all output voltages as E_1 or E_2.
b. Record angular settings Ø, and Ø2.

6.3.7 Linearity

6.3.7.1 Linearity to Plus and Minus 1g

a. Record output voltages E_1 and E_2.
b. Record all output readings taken at each 1g interval.

6.3.7.2 Linearity Above Plus and Minus 1g

a. At each increment record the following data:

1) Velocity of centrifuge
2) Radius of gyration (R) from the center of the centrifuge turning axis to the center of gravity (cg) of the accelerometer mass.
3) Voltage output (E_o) of the accelerometer

6.3.8 Scale Factor Constancy and Repeatability

a. Data shall be recorded as described in paragraph 6.3.7.

6.3.9 Cross Coupling

a. The accelerometer output shall be recorded at each level of acceleration applied.

6.3.10 Pick-Off Scale Factor and Spring Constant

a. Record the angle of rotation and the voltage output at each interval.

6.3.11 Quadrature Voltage

a. Record the quadrature voltage and the in-phase voltage.

6.3.12 Case Leaks

a. Record the reading of the indicator dial after evacuating to 0.5 inch hg and again after two hours of evacuation.

6.3.13 Tests Under Specified Environment

a. Data shall be recorded as specified in each test which is conducted.

6.3.14 Dielectric Tests

a. Room temperature adjacent to the unit shall be recorded.
b. Resistance values shall be recorded.

6.3.15 Spring-Mass Type Accelerometer with D-C Potentiometer

6.3.15.1 Potentiometer Resolution

a. Record the number of positive and negative steps shown on the chart.

6.3.15.2 Sensitivity Resolution

a. Record the difference in acceleration calculated from each change in table speed.

6.3.15.3 Static Friction

a. Record the angle through which the accelerometer was rotated.

6.3.15.4 Plus and Minus 1g Static Calibration

a. Record the polarity of both accelerations.
b. Record the two voltages measured.

6.3.15.5 Swept Length of Potentiometer Wiper

Record the Swept length measured.

6.3.15.6 Calibration, Repeatability and Linearity

a. Record voltage reading and table speed for each endpoint.
b. Record data as described in paragraph 6.3.7.2, at all calibration points.

6.3.15.7 Width of the Potentiometer Wiper

Record both resistances measured.

6.3.16 Gyro Integrating Type Accelerometers

a. Record whether or not friction and torque requirements between accelerometer and case and its mounting gimbal are compatible with the torquing capabilities of the servo system.
b. Record the effects of over pressure, under pressure and reliability of pressure operated switch.
c. Record the time for revolutions of the accelerometer's case about its gimbal and time for each 1/4 revolution.

d. Record the amount of drift for each position.

e. Record gyro wheel current and time for motor to come up to synchronous speed as well as its coast down-to-stop time.

6.3.17 Piezoelectric Type Accelerometers

6.3.17.1 First Method - Low Frequency

a. Record the outputs of both accelerometers
b. Record the frequencies of the shaker.

6.3.17.2 Second Method - High Frequency

Record the following data:

a. Output of accelerometer
b. Frequency of vibrator
c. Number of fringes observed in mirror

6.4 DATA REDUCTION AND PRESENTATION

An accelerometer being tested must meet all applicable specifications requirements for it to be suitable for use. All test results shall be compared to Qualitative Materiel Requirements (QMR) and Technical Characteristics (TC).

6.4.1 Visual Examination

No additional data reduction is necessary.

6.4.2 Resistance and Insulation

Consult the electrical schematic or applicable specification for resistance values and compare to those measured during test. Insulation values should conform to specification requirements.

6.4.3 Transfer Function, Frequency Response

a. A curve of g input versus voltage output shall be plotted from data obtained in paragraph 6.2.3.1.

> NOTE: The phase information from this test is not of high accuracy since the phase of the sine wave generator and motion of the pendulum have a complicated relationship, the discussion of which will not be covered in this MTP.

b. From the data obtained during this test, close approximations of the transfer function, damping factor, natural frequency can be obtained.

6.4.4 Damping Factor

a. Refering to the data obtained in paragraph 6.2.3.4, the amplitude of the over-shoot shall be divided by the amplitude of the step input as observed on the C.R.O.

b. The quotient obtained shall be applied to a damping factor curve, then a value of percent of critical damping can be determined.

6.4.5 Null Offset (E_n and Null Uncertainty

From the data obtained in paragraph 6.2.4, calculate the null offset as follows:

NOTE: Corrections for error tolerances shall be made. Amplitude responses and degree of critical damping shall be obtained.

a. The signal-to-noise ratio should be ascertained as accurately as possible. This can be done by dividing the null offset determined in paragraph 6.2.4, into voltages recorded during this test. Generally the ratio should be no less than 20 db.

b. When the shaker method is used the amplitude ratios and phase shift versus frequency shall be plotted on log-log or semi-log graph paper to give the Bode plot, from which the system time constants may be quickly estimated although not to a high accuracy.

Null offset is caluclated as follows:

$$E_n = \frac{E_2 - E_1}{2}$$

Where: E_n is null offset voltage

6.4.6 Sensitive Axis Alignment

Misalignment error in x-z axis equals

$$\frac{\emptyset_1 + \emptyset_2}{2}$$

and in the x-y axis is equal to

$$\frac{\text{difference between } \emptyset_1 \text{ and } \emptyset_2}{2}$$

The output voltage were recorded, but so far have not been used. They shall be kept for use in other tests. If there is no misalignment of the x-axis about the z-axis, the output E_1 obtained in paragraph 6.2.5.1, will be zero or null. Absolute zero may never be achieved since there may be a permanent null offset.

6.4.7 Linearity

The output of an accelerometer may be expressed by the following equation:

$$E_o = K\,F(a)\,a + E_n$$

Where:

E_o = Accelerometer output
a = Applied input acceleration
K = Accelerometer scale factor
F(a)= Linearity factor (a dimensionless quantity near unit in value) which is a function of "a".
En = Null offset in same units as output

Using the value E_n as determined in the test for null offset, values of K F (a) at + 1g and -1g may be determined, since the reference scale factor is generally determined at one g, the above constitutes the definition of scale factor K. This value of K shall be used to determine the indicated acceleration which is needed to calculate the linearity error.

Linearity error K F(a) is defined in percent as indicated acceleration minus applied acceleration when the K F (a) curve is normalized. Considering a plot of accelerometer output versus applied acceleration, a straight line is drawn, the origin and a point determined by the average for "a" of + 1g or - 1g. The linearity error is then considered to be the deviation of output from the straight line.

Where high accuracy results are required, the pendulus type accelerometers may change sensitive axis alignment with application of acceleration. This effect would show up in the less-than-one-g linearity test as a second order error superimposed on the nonlinearity error, provided the axis about which the pendulum swings is parallel to the axis of rotation during the test. This deviation can be noticed when the output error is plotted on a linear ordinate of a chart and the abscissa denotes the angle of rotation in degrees or radians.

Good test practice dictates that tests for linearity require two prerequisites:

Null offset (E_n) which was discussed in paragraph 6.4.5, and scale factor (K). Usually K is determined at ± g because a constant source of acceleration of this level is always available, namely; the earth's gravitational pull.

6.4.7.1 Linearity to Plus and Minus 1g

The reference scale factor shall be determined algebraically by:

$$K = \frac{E_1 - E_2}{2}$$

From the data obtained in paragraph 6.2.7.1, plot a ± g linearity curve, g input versus voltage output and determine the value of K as a function of acceleration as:

$$Kf(a) = \frac{E_o}{g}$$

Where:

K = Scale Factor determined at 1g

E_o = Output voltage at the different values of acceleration input, a.

a = Input accelerations, i.e., the 1g intervals

6.4.7.2 Linearity Above Plus and Minus 1g

From the data obtained in paragraph 6.2.7.2, plot a ± g linearity curve, g input versus voltage output and determine the value of K as a function of acceleration.

The data collected at each of the (a) increments shall be reduced to acceleration (a) and E_o and will provide one plot point on the linearity curve.

The equation for obtaining the input acceleration is:

$$a = \frac{Rw^2}{g}$$

Where:

W = Velocity of (cf) in radians per second

g = An acceleration unit generally referred to that acceleration imparted to a freely falling body by the earth's gravity pull. A commonly used value of g = 980 cm/sec^2 or 32.16 ft/sec^2.

R = Radius of gyration as has been explained, R should be measured in centimeters if the cgs system of calculating (a) is employed.

NOTE: A formula for reducing a centrifugal force to values of (a) when the F. P. S. system is used as follows:

$$a = \frac{4(\pi^2)\ N^2 R}{3600 \times 12 \times 32.16}$$

Where:

π = 3.1416

N = Speed in RPM

R = Radius of gyration, in this case 10 inches 32.16 = earth's gravitational unit

The formula simplified to:

$$a = 0.0000284N^2$$

6.4.8 <u>Scale Factor Constancy and Repeatability</u>

To determine scale factor constancy and repeatability consider the initial value of scale factor which was determined per paragraph 6.2.7. The accelerometer is now subjected to condition of environment, aging, temperature, etc., and scale factors for each new condition are determined. The new scale factor values are compared with the initial scale factor value. A curve of the differences can then be plotted and used to correlate the data.

6.4.9 Cross Coupling

If there was sufficient accuracy in the alignment, the cross coupling effect can be determined as:

$$C = \frac{a_n - a_1}{a_n - 1} \quad \text{in } g's/_g$$

Where:

C = Cross coupling

a_n = Indicated acceleration at n g's

a_1 = Indicated acceleration at 1 g

6.4.10 Pickoff Scale Factor and Spring Constant

On linear graph paper, plot a curve of the data recorded in step 6.2.9, e, output voltages versus angle of rotation, that is, E_o versus θ. For identification, encircle the plot points, thus ⊙, and denote this curve No.1.

It will be noted that the output voltage recorded in step 6.2.9 h, will by nature of the test, be the same as was obtained in step e, the dividing angle, θ, however, may be different by a small amount. Plot the data obtained in step 6.2.9 h, on the same graph but identify the plot points by placing them inside a box, thus ⊡, denoting this curve as No. 2.

There are now available sufficient data whereby for each given output value a pair of simultaneous equations which when solved, values for Ks and Ø can be obtained. An explanatory discussion follows where the following symbols are defined:

ml = Mass unbalance of the accelerometer proof mass (pendulum) in gm-cm

$\Delta\theta_I$ = Change in angle of the dividing head from the position of zero or null output voltage for test position 1 and curve 1. Angle should be expressed in radians (rad), 1 degree = 0.0174533 rad.

$\Delta\theta_{II}$= Change in angle of dividing head from the position of zero or null output voltage in test position II and curve II.

g = Acceleration force of earth's gravity

$$\left(\frac{cm}{sec^2}\right)$$

Ks = Spring constant of the spring-mass-suspension system

$$\left(\frac{dyne\text{-}cm}{rad}\right)$$

NOW: The data reduction discussed herein pertains especially to a force balance type accelerometer where the mass angular displacement will never exceed more than about eight minutes. This data reduction applies to other accelerometers besides the force balance types but in those cases, angular displacements will be larger and consideration of this fact is applicable to some of the mathematical expressions. The units of the pickoff scale factor are expressed in volts/g, milliampheres/g, etc. Spring constant units generally are expressed in g/radian, which is a function of the pendulum mass as well as the spring stiffness.

Consider:

For curve 1, the equation for the sum of the torques acting on the proof mass is:

$$Ks\ \emptyset = mlg \sin (\triangle\theta_1 - \emptyset)$$

For curve II, the sum of the torques is:

$$Ks\ \emptyset = mlg \sin \triangle\theta_{II}$$

Analysis of the above statements and of paragraph 6.2.9, reveals that voltage outputs, E_I and E_{II} are identical. The reasoning here is that the proof mass must turn through an identical angle $\emptyset$ in each case, to produce and identical value of output voltage E_o and E_{o11} was adjusted to equal E_{o1}. Now, since $\emptyset$ is in radians and since the maximum value of θ will not exceed about 8 arc minutes,

$$\sin \theta = \theta, \text{ and } Ks\ \emptyset = mlg\ (\triangle\theta_1 - \emptyset), \text{ also}$$

$$Ks\ \emptyset = mlg\ (\triangle\theta_{II}).$$

Thus, by substitution and transformation:

$$\emptyset = \triangle\theta_I - \triangle\theta_{II} \text{ and}$$

$$Ks = \frac{mlg(\triangle\theta II)}{\theta}$$

Thus, by solving for $\emptyset$ at several different values of output voltage ($E_{o\ II}$), a curve of the output voltage versus $\emptyset$ may be obtained. This curve is the scale factor of the pickoff.

Also, to obtain the value of the spring constant (Ks) in units of g's per radian, it is necessary to divide the expression for Ks by mlg because mlg is the torque associated with one g input acceleration.

Thus:

$$K = \frac{\Delta\theta_{II}}{\Delta\theta_{I} - \Delta\theta_{II}} \quad \text{in g's per radian}$$

6.4.11 Quadrature Voltage

Determine the phase shift angle,

$$\emptyset = \tan^{-1} \frac{\text{quadrature voltage}}{\text{in-phase voltage}}$$

6.4.12 Case Leaks

Due to a differential of nearly an atmosphere between the inside and outside of the case, the first reading of the dial indicator recorded should be quite a large displacement. If the second dial indicator readings are less than the first, a case leak is indicated.

If there is a difference in dial indicator readings, subtract the lower from the higher and record the result and "yes" on the data sheet. If the rate of case leak is desired further tests shall have to be conducted. If there is no leak, record "no" on data sheet.

6.4.13 Tests Under Specified Environment

The data obtained if method one is used, shall be compared to results of similar tests which were conducted under normal ambient room conditions. This is to determine the extent of degradation, if any, the specimen suffers while operating under the environmental conditions.

From the data obtained in method two, it is possible to determine whether the specimen suffered any permanent damage by having been exposed to the environment.

6.4.14 Dielectric Tests

Consult the electrical schematic or applicable specification for resistance values and compare to those measured during test.

6.4.15 Spring-Mass Type Accelerometer with D-C Potentiometer

6.4.15.1 Potentiometer Resolution

Determine the percent resolution by adding the steps and dividing into 100.

6.4.15.2

Referring to the data obtained in step h, of paragraph 6.2.14.2; if the three input changes are equal, record this value. If they are nearly equal (within ±5 percent), record the average of the three. If they are very dissimilar (greater than ±5 percent), record all three values.

6.4.15.3 Static Friction

Determine the amount of acceleration by reducing the angle to a g value as follows:

$$g = 1 \sin \emptyset$$

Where:

$\emptyset$ = Angle of rotation

6.4.15.4 Plus and Minus 1g Static Calibration

Sum the two voltages and record it, as the voltage change for ± 1g acceleration.

6.4.14.5 Swept Length of Potentiometer Wiper

If this test was not conducted because a spare accelerometer was not available, the data shall be obtained from manufacturer's literature applicable to the specific accelerometer of equal range and built to the same specification.

a. Using the swept length obtained determine the swept length per g as follows:

$$\text{Swept length per g} = \frac{\text{Swept length (inches)}}{\text{full range (g's)}}$$

The full range in g's can be obtained from the end points determined in paragraph 6.2.14.6.

b. Use this value obtained as the correction factor (r) to apply for correcting the radius of gyration (R) (See Appendix A, paragraph a), in calculating for the true g value in paragraph 6.4.14.6.

6.4.14.6 Calibration, Repeatability, and Linearity

a. Tabulate all data

b. By means of the formula for input acceleration (simplified) paragraph 6.4.7.2 reduce all rpm data to g values, and tabulate the values in the proper column on data sheet. These values are the apparent g's to which the accelerometer has been subjected and are designated as gw or working g's.

c. Compute gw to true g (gt) or "a" values as follows:

$$a \text{ or } gt = \frac{[R + r\,g\,w]\,gw}{R}$$

Where:

R = Radius of gyration
r = Swept length per g (paragraph 6.4.14.5)
gw = Working g's

d. Tabulate all gt values computed including the ± range from end points corrected to gt's.

NOTE: Unless otherwise stated, all further reference to g values pertain to the corrected true gt values as obtained from step c.

e. Take an average of the three identical tests and tabulate on data sheet.

f. Check back over the three tests, note and record the two instances, negative and positive, where in the calibration data deviated the greatest amount from the average. This is an indication of accelerometer repeatability and linearity characteristics.

g. Plot on a prescribed sheet the values of output voltages versus input g as obtained from step c.

h. Plot the average of the calibration points obtained under conditions of decreasing speed or deceleration.

1) Enclose all plotted points obtained under increased acceleration, by a small circle, ⊙.
2) Enclose plotted points of deceleration by a small triangle △.

i. Plot on the same sheet, the calibration line which is the best straight line passing through the average output voltage at zero input and through the average plot points of the average output voltages.

j. Plot on the same sheet, the specified tolerance envelope.

k. Hysteresis Error

1) Refer to test data sheet and determine the greatest deviation in the columns of averages, where in like calibration points differ.
2) Reduce this deviation to terms of voltage ratio.
3) Tabulate this value on a data sheet and curve as the hysteresis error. (This may be expressed in percent if preferred).

6.4.14.7 Width of Potentiometer

The difference in the resistance values measured in paragraph 6.2.14.7 is the amount shorted out by the wiper. The width of the wiper is determined as follows:

$$\text{width of wiper} = \frac{\text{resistance when wiper is isolated} - \text{resistance of potentiometer}}{\text{number of ohms per wire}}$$

The number of wires can be found from manufacturer's literature. The number of ohms per wire is determined as follows:

$$\text{ohms per wire} = \frac{\text{resistance measured when wiper is isolated}}{\text{number of wires}}$$

6.4.15 Gyro Integrating Type Accelerometers

Except for "Linearity of Precession" no additional data reduction is necessary for the additional tests peculiar to this type of accelerometer.

Determine linearity of precession by comparing the timing in seconds of all the fractions of revolutions.

6.4.16 Piezoelectric Type Accelerometer

6.4.16.1 First Method, Low Frequency

a. Plot a response curve (voltage vs. frequency) for both accelerometers.
b. By comparing the response curves comparative performance values as well as calibration can thereby be obtained.

6.4.16.2 Second Method, High Frequency

a. Compute displacement at each interval as follows:

$$d = \frac{n\lambda}{2}$$

Where:

λ = Wavelength of monochromatic 1
n = Number of fringes observed

b. Compute acceleration at each interval as follows:

$$g = df^2 x\ 0.0511$$

Where:

d = inches
f = cps

c. Plot two curves frequency versus calculated acceleration and frequency versus accelerometer output.
d. Accelerometer performance shall be obtained from comparison of these two curves.

APPENDIX A

DESCRIPTION OF ACCELEROMETERS

To detect the degree and direction of trajectory change,use is made of accelerometers. An accelerometer is an inertia device. The field of accelerometry is not new, and a great number of devices for measuring static and dynamic accelerations is used. The basic principle of operation of an accelerometer consists of the measurement of the inertial reaction force of a mass to an acceleration. Many different methods can be used in measuring this force. The choice of the method is mainly dependent on the frequencies present, whether or not acceleration is changing, and the type of output that is desired.

There are two principal types of accelerometers. In the first type (spring mass type) the inertial reaction force of the mass causes a displacement of the mass in elastic mounting system. The displacement is then measured by one of several methods. The second type (force balance type) of accelerometer operates on a fundamentally different principle. The force that counteracts the inertial reaction force of the mass is not supplied by an elastic mount but supplied by an electric current, a stream of air, or any other system which can produce a controllable force. In this system, a small deflection of the mass is detected and a force is instantly applied to the mass to prevent any further motion. Acceleration is indicated by the magnitude of the force applied to the mass by the electric current or whatever other means is used to produce the balancing force.

In order to have an efficient spring mass type accelerometer, it is necessary that the amount of damping applied to the system be just enough to give a non-restricted displacement and yet prevent any oscillations from existing.

If the missile suddenly accelerates some distance the mass is displaced (relative to the missile). There is also a certain displacement of the spring per unit of force applied. At the end of the period of time that the force is applied the spring tends to reverse the direction of the force on the mass. This would lead to simple harmonic motion if allowed to stand alone. Therefore, the damper is used to produce an action that limits this oscillation. The damper must attain a certain velocity at the end of this time so that its retarding action will counteract the force set up by the spring as a result of the displacement of the mass. The damper will again present such a counteracting force when the mass has reached its maximum displacement in the opposite direction. Displacement in the opposite direction is due to the force exerted by the spring.

The accelerometer should operate in the underdamped region (when damping action is less than the tendency of the spring to sustain oscillation) bordering the critically damped condition when the damping action equals the tendency of the spring to sustain oscillation). This gives us a system that is sensitive, and at the same time the system tends to prevent any transient oscillations. The accuracy of the system depends on the method used to measure the displacement of the elastic mounting. The sensitivity of the system may be increased by reducing the frictional forces in the mounting and by improvement of the indicators used.

Figure A-1, shows force balance type of accelerometer in which the force that counteracts the inertial reaction force of a mass is not supplied by an elastic mount but is supplied by an electrical current.

Let "e" be a voltage that is developed due to the displacement of the mass relative to the missile and "i" the output of the amplifier (the restoring current fed to the coil).

If "e" is dependent on the displacement of "y" of the accelerometer mass (m), then the output of the amplifier (i) is dependent on the displacement (y). If the missile accelerates there is a certain voltage applied to the amplifier input. After necessary amplification there is a proportional output applied to the amplifier input. After necessary amplification, there is a proportional output applied to the coil in such a way as to counteract a certain amount of the displacement. As the mass (after initial acceleration) tends to move in the opposite direction, another restoring current is generated.

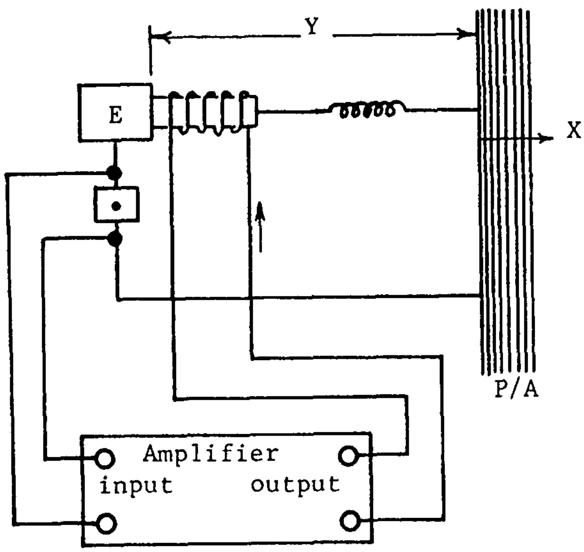

Figure A-1. Accelerometer in Which Inertial Reaction Force of a Mass is Supplied by an Electric Current.

The acceleration, therefore could be measured by the displacement, by the input to the amplifier, or by the restoring force of the current fed to the coil.

The displacement allowed to the mass is small, which means that errors which may arise due to the nonlinearity of the electric field are mostly eliminated. The sensitivity of such a system can be increased with little effect on the range of operation.

There are many other ways of measuring the acceleration of a missile. The methods just discussed are just two samples of the many ways to accomplish this function.

The following paragraphs contain descriptive data for those accelerometers for which procedures peculiar only to those types were dealt with in detail in this pamphlet

a. Spring-Mass Type Accelerometers with D-C Potentiometer Pickoff - This type of accelerometer is different from the two types (spring mass and force balance); just discussed in that it does not operate in a closed loop servo mode; therefore there are no forces acting to counteract the mass movement during accelerations except the spring rate of the mass-spring seismic system. Consequently, the mass moves or creeps directly with the applied acceleration and the amount of movement is limited by the spring. It follows then that a test is necessary to determine the amount of mass creepage during acceleration tests since a compensating correction will have to be applied. The creepage will have the effect of lengthening the radius of gyration (R).

b. Gyro Type Integrating Accelerometer - This type of accelerometer may be considered to be a single-axis gyro alignment loop in which an intentional unbalance is created in the gyro rotor by affixing an unbalance weight on to the precession axis which is the gyro inner gymbal. In most cases, the inner gimbal is in the form of a cylinder floating on air bearings. This unbalance is termed pendulosity and is the product of the unbalance mass multiplied by its moment arm as measured from the gyro's precession axis. An acceleration along the input axis causes motion about the precession axis beacuse of the mass unbalance. There is an electrical pickoff attached to the inner gimbal. Mounted in a gimbal, the gyro is a part of a null-seeking servo loop in which motion about the precession axis is detected, amplified, and fed to the gimbal torquer to cause a relative motion between the gyro gimbal and its case. The gyro case rotates. The torquer is positioned along the gyro's input axis and drives the loop to null. When this occurs, the gimbal-case angular motion is equivalent to the integral of the acceleration input. There is a second electrical pickoff (usually a synchro) which measures the position of the gyro case as it has been rotated by the above mentioned servo action about its mounting gimbal. This means then, that the synchro output signal is a velocity signal. Thus, the final output signal is equivalent to the first integration of the acceleration of the accelerometer's inputs.

c. Piezoelectric Type Accelerometers - This type accelerometer is light weight and minature in size, some being the size of a thimbal or smaller. As the name implies, it is self generating and its crystal bulk provides its own mass. These accelerometers have a minute output per g, and always operate in connection with their own coaxial cable cathode follower and amplifier. Amplifiers usually are adjustable for a selective gain of 10, 30, and 100. The final output may be on the order of from 4 to 100 millivolts per g or more, at the present state of the art. Due to internal leakage of the crystals, this type accelerometer is limited in low frequency to about 16 cps, or sometimes lower, but it is a characteristic that they are extremely linear in response from their low frequency range limit up to several thousand cps since their natural frequency may be as high as 10 kc. The accelerometer generally is used for measurements of vibration; therefore, centrifuging is never employed in test evaluation except environmental tests. These accelerometers are used extensively in telemetry for measuring missile vibration levels. They are not considered a high accuracy type accelerometer.

APPENDIX B

SENSITIVE AXIS ALIGNMENT

Alignment of the sensitive axis of an accelerometer with respect to the reference surfaces becomes an important factor when dealing with high precision surfaces on the case of the accelerometer. In some accelerometers, there is only one electrical reference designated during assembly.

As misalignment and cross coupling give, in large measure, the same error indication when subjected to cross axis forces, the two terms misalignment and cross coupling must be clearly defined.

All linear, single-axis accelerometers have two perpendicular planes with respect to the mounting surface wherein misalignments are possible. One of these planes, which will be denoted the No. 1 or X-Z axis, and represents the alignment between the movement of the mass or pendulum in the sensitive direction (see Figure B-1) with respect to layout of reference surface mounting holes. The other plane, which is perpendicular to the No. 1 plane, is denoted as No. 2 or X-Y axis. Y is also the pendulum pivot axis. This plane represents the parallel alignment between the horizontal planes, of the mass and the reference mounting surface. An accelerometer has still a third axis, denoted the Z axis, which is perpendicular to both the X and Y axis. To sum up and clarify what has been said, let it be stated in other words:

Plane No.1 represents alignment of the X-axis about the Z-axis. Plane No. 2 represents alignment of the X-axis about the Y-axis.

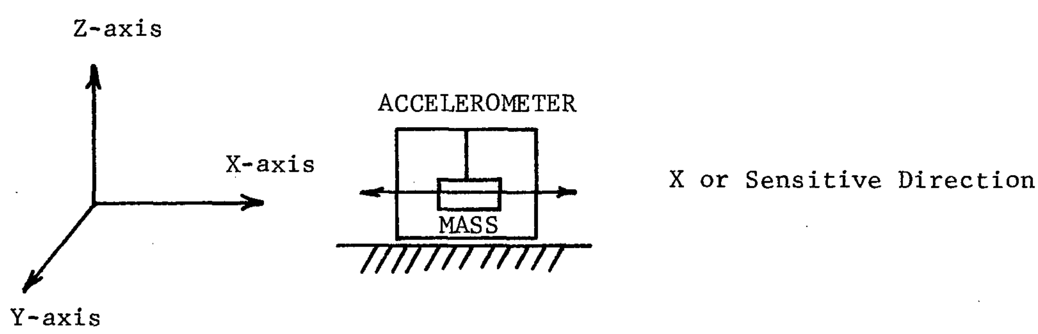

Figure B-1. Accelerometer X-, Y-, and Z-Axis Relationship.